Received: 4 July 2018 | Revised: 3 February 2020 | Accepted: 25 February 2020

DOI: 10.1111/joac.12360

ORIGINAL ARTICLE

Journal of Agrarian Change WILEY

From a free gift of nature to a precarious commodity: Bees, pollination services, and industrial agriculture

Rebecca A. Ellis[1] | Tony Weis[1] | Sainath Suryanarayanan[2] | Kata Beilin[3]

[1]Department of Geography, The University of Western Ontario, London, Ontario, Canada

[2]Center for Culture, History and Environment, Nelson Institute for Environmental Studies, and Holtz Center for Science & Technology Studies, University of Wisconsin-Madison, Madison, Wisconsin

[3]Department of Spanish and Portuguese, Nelson Institute for Environmental Studies, and Holtz Center for Science and Technology Studies, University of Wisconsin-Madison, Madison, Wisconsin

Correspondence
Rebecca A. Ellis, Department of Geography, The University of Western Ontario, 1151 Richmond St, London, ON N6A 3K7, Canada.
Email: rellis23@uwo.ca

Funding information
Social Sciences and Humanities Research Council of Canada, Grant/Award Number: 752-2017-2174

Abstract

The growing crisis of bee health has shone a spotlight on the problems facing pollinator populations in many parts of the world, the worrying implications for agriculture and ecosystems, and some of the risks of pesticides. Although this attention is important and can open a range of critical vistas, the threats to bees, other pollinators, and the future of pollination are too often framed in narrow ways. The goal of this paper is to provide a systematic way of thinking about the crisis of bee populations by examining the changing dynamics of pollination within industrial agriculture, drawing heavily on transformations in the United States and Canada. We set out a case for understanding pollination as a biophysical barrier to industrial organization and the rise of pollination services as a response that temporarily fixes (or overrides) this barrier, while containing an internal set of contradictions and overrides. We argue that these dialectic relations are continually generating further problems and hope that this lens can help inform critical education, outreach, and movement building with respect to the urgent problems of bee and pollinator health. In particular, we stress the need to connect growing bee-related advocacy with struggles to confront industrial capitalist agriculture.

We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

KEYWORDS
beekeeping, bees, industrial agriculture, political ecology, pollination

1 | INTRODUCTION

Attention to the crisis of bee populations is growing, reflected in political struggles over pesticide regulations, news media coverage, documentary films, grassroots activism, and even a food company advertising campaign.[1] The mysterious problem of colony collapse disorder (CCD) has clearly moved beyond the scientific literature to some level of popular consciousness since it was documented as afflicting the honeybees (*Apis mellifera*) in the United States.[2] This has spurred awareness of honeybee vulnerability (Durant, 2019) and of more generalized declines and ill-health of native bee populations (Goulson, Nicholls, Botias, & Rotheray, 2015). It is important to recognize that the widespread problems facing bees are part of but not synonymous with the crisis of pollination, which refers to documented declines in a range of key pollinator species and plants that depend upon them, posing problems for both agriculture and ecosystems (Potts et al., 2010).[3] Further, this is unfolding within an even wider context of global insect population declines (Hallmann et al., 2017; Lister & Garcia, 2018). These declines are driven by a series of interlocking factors, including climate change, habitat loss, changing pathogen dynamics, invasive species, and pesticide use (Hallmann et al., 2017; Lister & Garcia, 2018; Potts et al., 2010). Growing recognition of the risks posed by pesticides has led to pressure for precautionary regulation in a range of settings (Suryanarayanan & Kleinman, 2014; Vogt, 2017).

Despite growing attention, there is cause for concern that much of the coverage of bee declines pivot around narrowly defined technical evidence (especially in relation to the harm caused by a specific class of pesticides) in a way that can obscure the more fundamental roots of the problems, along with the need for much bigger changes. A basic premise of this paper is that while conditions affecting bee health and threats to survival are well studied, and evidence is proliferating, too often the problems facing bees are assessed and presented in isolation, with insufficient attention given to the range of ways that industrial agriculture bears on them and how these interrelate. Another premise is that the worsening conditions of bee health and the dynamics of pollination warrant attention in critical agrarian studies, as they are one more tenuous aspect of the immense productivity of industrial agriculture and the cheap food it generates. Our primary goal with this paper is to provide a systematic way to think about the radical transformation of pollination within industrial agriculture in the hope that illuminating key socio-ecological interrelations can inform critical education, outreach, and movement building. To this end, we conclude by considering how the rising consciousness about bees might be mobilized in anti-systemic directions by radical social movements and by examining some important related struggles that are now stirring.

[1]The battle at the European Commission has been the highest profile contest over pesticide regulation (Carrington, 2017), which has also made waves in other justifications like the province of Ontario in Canada (Benzie, 2015). In the United States and Canada, the growing momentum for "Bee City" certifications is one response to popular pressures at the municipal scale. Also notable is the "Bring Back the Bees" advertising campaign for Honey Nut Cheerios www.cheerios.com/BringBackTheBees.

[2]With CCD, most of the worker bees disappear without dead bodies or telltale signs of a swarm, an event that occurs when the colony decides that it is too big for its hive or in response to pest and pathogen pressures. When bee colonies swarm, roughly half of the colony leaves with the old queen to find a new nesting site. The remaining worker bees create a new queen. CCD was documented most heavily in the United States, starting in the mid-2000s, and the attention this drew has been largely sustained despite incidents diminishing after around 2014.

[3]Although there is compelling evidence that bees are a central part of the pollinator crisis, there is also considerable uncertainty. For instance, of the 20,000 species of bees in the world, most are not studied by scientists, and so their health and population size are unknown. Although some species of bees are flourishing, there are indications that other species of bees are facing either declining populations or ill-health (Goulson et al., 2015).

2 | THE BIOPHYSICAL CONTRADICTIONS OF INDUSTRIAL CAPITALIST AGRICULTURE

Our approach focuses on how political economic imperatives shape the organization of productive environments and the species within them, including the manipulation of bodies. The pursuit of industrial scale relates to an elemental competitive discipline in capitalist economies: Because of the pivotal role of labour in generating surplus value, owners of capital must continually search for ways to increase its productivity, and the pressure to substitute capital inputs drives relentless cycles of technological innovation in the production process (Moore, 2010). These imperatives are entwined with the biological simplification and standardization of agricultural landscapes, which is evident in the industrial grain–oilseed–livestock complex from tractors and combines on massive monocultures to the cages, stalls, and automated feeding systems in densely packed livestock operations (Weis, 2010, 2013). The pursuit of industrial scale in agriculture has clearly been successful in certain ways, most of all with immense increases in labour productivity (output per worker) and yield (output per plant and animal), which is reflected in rising volumes of cheap food over many decades (Berenstein, 2010; Sage, 2012). However, the biological standardization and simplification needed for labour-displacing machinery tend to exacerbate chronic challenges for agricultural production or engender new ones. This includes problems such as increased erosion, reduced soil organisms and moisture, amplified demand for water, the inability to save hybrid or genetically engineered seeds, heightened risks of insect and weed infestations and infectious disease, worsened animal health, and vast concentrations of animal excreta. In other words, there are a series of interrelated *biophysical barriers to scale* in agriculture (Mann & Dickinson, 1978; Weis, 2010).

For industrialization to proceed, barriers to scale must be conceived as discrete phenomena and perpetually managed through various purchased inputs including fertilizers, seeds, irrigation, herbicides, insecticides, fungicides, miticides, antibiotics, vaccines, and disinfectants, which must often be moved over considerable distances. In addition, the distance outputs must move necessarily increases the more landscapes are specialized. The intractable dependence on inputs and the long-distance flows of inputs and outputs involves an extensive resource budget, with fossil energy coursing through industrial agricultural landscapes from the powering of large machines to the manufacture and movement of fertilizers and pesticides. It also involves a diffuse set of unaccounted pollution loads, including greenhouse gas (GHG) emissions, persistent toxins, and nutrient loads that destabilize aquatic ecosystems (Kimbrell, 2002; McIntyre, Herren, Wakhungu, & Watson, 2009; Sage, 2012; Weis, 2010, 2013). The fact that various inputs indefinitely mask but never sustainably resolve the underlying problems is why they are often described as "treadmills" in critiques of industrial monocultures and livestock operations.

Yet while the image of treadmills is effective in conveying perpetuity, it can also give a false sense of steady, straightforward motion and understate both the deepening of underlying problems (e.g., continuing soil erosion, salinization of over-irrigated soils, and the loss of natural pest controls) and the unforeseeable long-term risks, including the untestable and unquantifiable dynamics associated with chronic input use. One glaring instance of these risks is the fact that insects, weeds, fungi, mites, and bacteria struggle to evolve in the face of the inputs geared to control them, and as resistance emerges through the survival and procreation of hardier organisms, it poses dynamic challenges for agrochemical and pharmaceutical development. Inputs can also adversely affect other problems than those they are responding to, such as pesticides diminishing the health of soils. Rather than treadmills then, industrial monocultures and livestock operations are better understood to hinge on indefinite attempts to override the biophysical barriers to scale, as underlying problems deepen and fierce new ones are unleashed. In short, *biophysical overrides* can enable great labour productivity gains for a time, but their durability is never assured as the barriers to scale are never fixed (Weis, 2010, 2013).

Taken together, industrial capitalist agriculture is characterized by abiding *biophysical contradictions*, with productive environments organized in a way that actively undermines their long-term viability. The irrationality and precarity of these dynamics are partly obscured by the uncertainty about when overrides will break down.

For instance, when will soils become too impoverished of nutrients and organisms for fertilizers to work? When will the supply of key resources (e.g., oil and phosphorous ore) run out? When will resistance to widely used insecticides, herbicides, or antibiotics emerge? When will the decline of aquifers or rivers reach a point where it compromises the viability of irrigation? Added to this are the immense risks posed by climate change, to which industrial agriculture is a major contributing factor. For as long as biophysical overrides continue to function, and their long-term costs go unaccounted, cheap bountiful production is possible. But when biophysical overrides stop working or become more expensive in economic terms (e.g., if resources become scarce or if externalities like GHG emissions are ever aggressively taxed), the fundamental contradictions can be seen to be accelerating (Weis, 2010).

Our contention here is that widespread declines in the health of bee populations and increasing challenges of pollination must be understood in relation to the pursuit of scale and the pressure to override biophysical problems in industrial capitalist agriculture. To establish this case, we take an inductive approach that benefits from our experience with beekeeping and bee advocacy, research on a range of related subjects (including industrial livestock production, urban beekeeping, bee social behaviour, and bee–human intimacies in small farming systems), and diverse disciplinary backgrounds (in political ecology, geography, entomology, science and technology studies, and the environmental humanities). We begin with an overview of the diversity of bee–human interspecies relations prior to industrialization, which were often mutually beneficial, but which should also not be romanticized. This discussion also considers how some early innovations in beekeeping helped lay the foundation for subsequent intensification. We then reflect upon the major ways the organization of industrial monocultures affects bee health and prospects for survival and how this reverberates on the growing demand for pollination in certain biologically simplified landscapes. This has in turn given rise to commodified pollination services and the long-distance trucking of bee colonies, a subsector that few people probably even realize exists. Although the crisis of pollination has global dimensions and the contradictions are structural, we draw heavily on the historic transformations and contemporary problems in the United States and Canada, as these are among the most industrialized agricultural systems in the world and accentuate the contradiction-and-override dialectic with pollination in especially stark terms.

Our core argument is twofold. First, the demand for pollination is a barrier to scale for certain crops that has led to the rise of pollination services, which constitutes an underappreciated biophysical override in industrial capitalist agriculture. Figure 1 locates pollination within the broader biophysical contradictions of industrial capitalist agriculture. Second, this new subsector is beset with its own barriers to scale, illustrated in Figure 2, as the unnatural conditions facing bees engender both immediate problems that must be overridden and complex long-term risks. There are many indications that these dynamics are becoming more precarious—or that the contradictions of commodified pollination services are accelerating—with untold social and ecological consequences.

3 | NON-INDUSTRIAL POLLINATION: UNMANAGED AND PARTLY MANAGED INTERSPECIES RELATIONS

For the vast majority of agrarian history, pollination for agriculture occurred both as a "free gift" of nature and as a partially managed interspecies relation. Where it amounts to a free gift of nature, pollination essentially involves unmanaged interspecies relations with various bee species (of which there are over 20,000 around the world) along with an array of other species, such as butterflies, moths, wasps, hoverflies, beetles, and hummingbirds. While there are many animals that pollinate flowers, bees as a group are the most efficient pollinators (Food and Agriculture Organization, 2018). Honeybees are not necessarily the best pollinators among bees, and in fact, many other bees are more efficient pollinators of certain plants, including range-restricted plants (Norfolk et al., 2018) and some crops

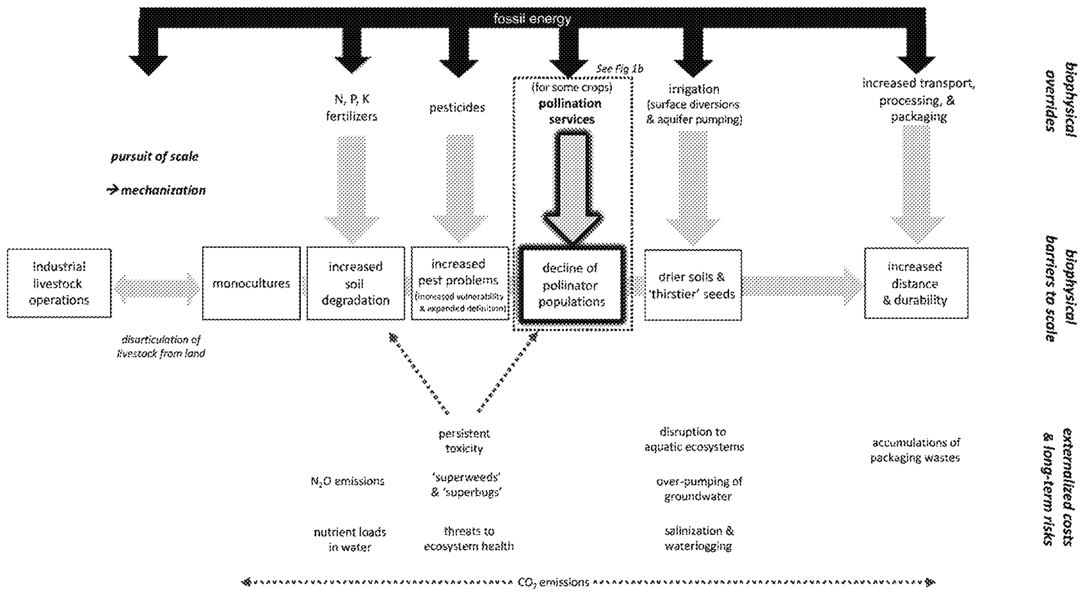

FIGURE 1 Locating pollination in the biophysical contradictions of industrial agriculture. *Source*: Adapted from Weis, 2010, 2013

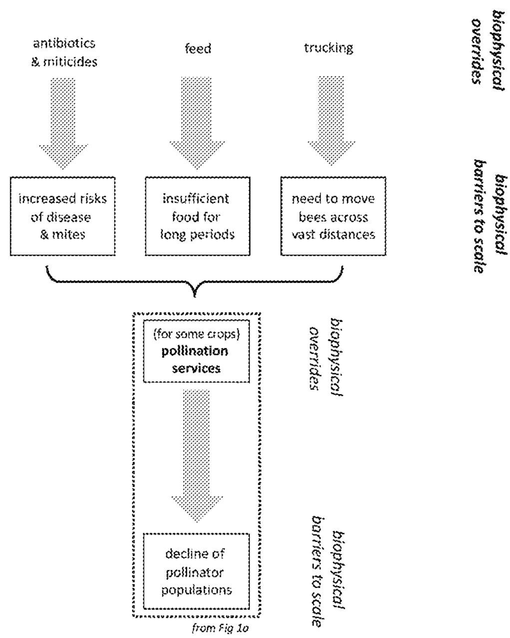

FIGURE 2 Biophysical contradictions of pollination services. *Source*: Adapted from Weis, 2010, 2013

(Nicholson & Ricketts, 2019). However, the dynamics of managed pollination centres on honeybees, with *A. mellifera* the most common species of honeybees that is managed throughout the world.[4]

[4]Other species of bees that are managed by humans include some species of bumble, mason, and leafcutter bees. However, they are not managed on the scale of *A. mellifera*.

Initially, the main way that people engaged with honeybees was to periodically "hunt" for honey from wild bee nests, and in some places, it was common for families to have customary ownership over a wild honeybee nest, practices that continue today in some parts of Southeast Asia, Africa, and Eastern Europe (e.g., Tsing, 1995). The earliest evidence of artificial nests was found in parts of Southeast Asia, built for a large-bodied species of honeybee, *Apis dorsata*. *A. mellifera* began to be semi-domesticated about 7,000 years ago in Egypt, through the management of colonies in human-created hives, and for thousands of years, small-scale beekeeping was common in northern Africa, the Middle East, and parts of Europe, including in cities, with bees kept primarily for their honey and beeswax (van Engelsdorp & Meixner, 2010; Crane, 1999).[5]

Much of the long, shared history of humans and honeybees can be understood as a mutually beneficial interspecies relation. Honeybees were not intensively managed, were allowed to swarm, and often went feral.[6] Their proximity to a range of crops helped to ensure a stable food supply, while humans benefitted from bee products and the pollination they provide. Honeybees have characteristics that have made them relatively easy for humans to manage for honey and other bee-created products. At the same time, honeybees have made great pollinators because they are generalists, gathering nectar and pollen from a wide variety of plants and foraging over an average of close to 5 km in search of food sources. Honeybees are social insects who live in large colonies of 10 to 60,000 individuals, with about one third of the colony being foragers. Some *Apis* species have adapted well to human-made hives and expand the size of their colony with increased room and food. *A. mellifera* (the Western honeybee) is the most widely managed honeybee in the world. *Apis cerana* (the Eastern honeybee) is widely managed in parts of Asia but is being replaced by *A. mellifera*. Although *A. mellifera* is more susceptible to pathogens and viruses, *A. cerana* swarms regularly, has smaller colonies, and produces less honey than *A. mellifera* (Park et al., 2015).

In contrast, most non-managed or "wild" bees, whether solitary or social insects, do not live in colonies. Exceptions are bumble bees who maintain small colonies of a few hundred individuals and multiple stingless bee species who also live in large colonies on par with social *Apis* species. Non-apis wild bees tend to forage over shorter distances, some within a radius of only a few hundred metres of their home, finding habitat either in the pithy stems of perennials or in the ground. Wild bees include both generalists and specialists, the latter having co-evolved with certain plant families (e.g., the squash bee exclusively gathers pollen and nectar from plants in the squash family). The interspecies relationship between humans and bees is thousands of years old and has often been a mutually beneficial one, though probably benefitting humans to a greater degree. Humans have long extracted and used the products of honeybee hives (honey, beeswax, pollen, and royal jelly) for both food and medicine, and bee pollination—both managed and wild—played a key role in the diversification of agriculture and diets in many parts of the world. Pollinator-dependent crops have a crucial part in balanced human diets, offering micronutrients such as Vitamins B and C and folic acid (Potts et al., 2016), at the same time as many agrarian practices offered (and continue to offer) both managed and wild bees a wide variety of forage and habitat.

Most of the fruits, vegetables, herbs, and flowers humans cultivated over the past few thousand years provide an abundance of nectar and pollen for bees, and a wide variety of bee species have long found habitat in diverse smallholder farms, including in snags, woodland areas, orchards, woody herbaceous perennials, and patches of dirt. The geographic range of *A. mellifera* and, to a lesser extent, *A. cerana* expanded greatly once they were managed by humans. The social and cultural significance of bees, especially honeybees, is reflected in the fact that they are referenced in sacred texts within Islam, Christianity, Buddhism, and Hinduism (Potts et al., 2016), and the presence of bee-related gods or goddesses was common to many cultures who practised beekeeping or honey hunting. Furthermore, honeybees have inspired both artists and architects for millennia, and benign conceptions of the social

[5]Before the rise of large-scale sugar production, honey was the primary sweetener in these regions.

[6]If a bee swarm is not caught by a beekeeper, they will find make a nest in a cavity such as a tree truck or the wall of a building. These colonies can be considered feral as they are no longer managed by beekeepers and often live undetected by people for long periods of time, sometimes for the entire lifespan of the colony.

organization of honeybee colonies (i.e., as relatively egalitarian and democratic) inspired some historical thinking about democracy in human societies (Seeley 2010).

The interspecies relations between humans and bees should not be overly idealized, however, as some patterns of violent exploitation of honeybees by humans preceded industrialization. For instance, a common practice that arose in Europe was to kill the entire colony at the end of the growing season to gather the honey and beeswax and then seek to replace it with a feral swarm the next spring, a practice that moved across the Atlantic with European colonists (Crane, 1999). Honeybees were first brought to the eastern coast of the United States and Canada by European colonists in the 17th century, and they subsequently advanced with and more often ahead of colonial settlements, through natural swarming (Crane, 1999). Artisanal beekeeping became common for both farmers and people living in towns, keeping a beehive or two in straw skeps or wooden hives and largely using the products for household consumption (Oestrel, 1980). The use of skeps also allowed for more wild swarming of bees than later techniques.

As colonialists tore into the forest frontier of the United States and Canada to make way for agriculture, the cheap, abundant stores of lumber contributed to developments in hive design, culminating in a new wooden hive design by L.L. Langstroth in 1852 that consisted of stackable boxes and moveable frames (Oestrel, 1980). The Langstroth hive allowed for more intensive control and manipulation of bee colonies: Colony sizes could be enlarged by increasing the number of stacked boxes and moving comb-frames, which also served as a key part of beekeeping strategies to overcome the biological barrier of swarming; queen bees could be more easily bred (with commercial implications); and honey could be more easily removed without killing the bees (Crane, 1999). The curtailment of swarming in the pursuit of scale arguably created unanticipated in-hive conditions for the spread of never-before documented bacterial and fungal bee diseases (Pellett, 1938; but see van Engelsdorp & Meixner, 2010). The emergence of biophysical contradictions such as bacterial foul brood disease and unexplained disease epidemics in the late 19th century may have further promoted overrides in various forms including burning colonies, breeding resistant strains of queens, and, later on, the prophylactic use of antibiotics and fungicides. Nevertheless, the Langstroth hive remains the most common hive design used by North American beekeepers today, and while beekeepers initially continued to also be crop growers and dairy producers after its development, the amplification of the increasingly industrialized scale of honey production set the stage for the emergence of beekeeping as a specialized profession (Oestrel, 1980) and for its industrialization.

While the developments in beekeeping that led to the scaling-up of honey production were interconnected with the rise of queen breeding, another trigger for the increased selling and shipping of queen bees within the United States stemmed from a ban on all importations of new queen bees from Europe in 1922 in order to control the spread of European Foulbrood (Oestrel, 1980). The rise of a queen breeding industry within both the United States and Canada was an important aspect of the rapid commercialization of beekeeping in the 1920s, along with dramatic improvements in highway infrastructure and motor vehicles (Crane, 1999). At first, the commercialization of beekeeping was focused on increasing the scale of honey and other bee products for sale beyond household consumption, but the ability to ship queen bees and hives over great distances soon took on a more crucial economic function (Oestrel, 1980).

4 | POLLINATION AS CONTRADICTION WITHIN INDUSTRIAL AGRICULTURE

Pollination emerges as a significant contradiction with the industrialization of agriculture for three principle reasons. First, crops that depend upon bee and other insect and bird pollinators are not conducive to extensive monocultures because this tends to increase the demand for pollination beyond what can be met by small-scale beekeeping or native bees. This basic challenge of insufficient pollination is also obviously acute in commercial greenhouse operations. Further, while native bees have been important pollinators in different farming cultures, many are ill-suited to large-scale monocultures due to species-specific traits, such as specialized diets (e.g., seeking nectar mainly or entirely from forest flora) or because they will only fly a short distance from their habitat to forage.

The second major reason why pollination presents a barrier to industrial-scale agriculture relates to the unpredictability of honeybees. While long histories of beekeeping have influenced honeybee behaviour and genetics, and they are now managed on very large scales, it is important to recognize that honeybees are at most only semi-domesticated, and their activity is not entirely predictable. Part of their unpredictability relates to the complex sociality of the honeybee colony, which has been called a "superorganism" (Seeley, 2010). Beekeepers have observed that colonies can exhibit "personalities" at the scale of the collective, which implies a level of individuality that is different from an individual bee (Moore & Kosut, 2013). Seeley (2010) argues that bee colonies are a complex society that functions as an "integrated whole," with colonies engaging in complex decision-making, with a well-known example being the decision to swarm and the selection of a new home.[7] Although there are techniques to dissuade a bee colony from swarming, a bee colony will make the decision to swarm independent of beekeepers' desires, a dynamic which complicates the status of bee colonies as property of the beekeeper; for instance, a swarm could end up in a tree (Seeley 2010), the attic or walls of a home, a compost bin, or being captured by another beekeeper.

This unpredictability relates in large measure to the lifecycle of the colony, which includes at least one yearly swarm. Swarms generally fly within 150 m of their hive and send out scout bees to locate suitable spots for a nest. If they are not caught by a beekeeper, they will find a nesting spot, often in spaces that mimic the tight quarters of the inside of a hollow or rotting tree (Seeley, 2010). Beekeepers try to avoid swarming by regularly expanding or splitting hives, but this honeybee behaviour remains a common challenge for beekeeping operations of all sizes. Although beekeepers tend to be vigilant in catching swarms in their vicinity, managed honeybees still regularly go feral (Seeley, 2010).[8] This unpredictability is obviously exacerbated by the growth in the scale of beekeeping practices.

The unpredictability of honeybees has been further augmented by a few notable introductions of different species to new bioregions and the ensuing hybridization. The hybridization of honeybees that has drawn the most attention outside of the beekeeping community is the hybridization with so-called "Africanized" or "killer" honeybees, which are a hybridization between subspecies of *A. mellifera* and the African honeybee *A. mellifera scutellata* (also a subspecies of *A. mellifera*). The African honeybee was introduced in Brazil in the 1950s in order to increase honey production in a controlled environment but were accidently released into the "wild" (Lin, McBroome, Rehman, & Johnson, 2018). African honeybees were attractive because they produce more honey than Western honeybees, but they also have stronger defensive behaviour patterns and are quicker to act and more persistent in driving away potential dangers, including beekeepers. This makes hybridized bee colonies in Central and South America and the Southern United States potentially more difficult—and more dangerous—to manage, adding to their potential unpredictability.[9]

The third great problem of pollination associated with industrialization relates to the loss and degradation of pollinator habitat (Durant, 2019). Overall habitat loss—both on- and off- agricultural land—is greatly amplified by the excessive land devoted to agriculture as a result of cycling feed crops through fast-rising livestock populations, a system that commands roughly one third of the world's arable land that is an extremely inefficient way of generating usable nutrition. In other words, far more forests, grasslands, and wetlands have been converted to agriculture than is necessary to meet human nutritional needs, and the persistence of these wasteful flows of feed through industrial

[7]In his terms, a honeybee swarm "performs decision-making when it obtains information about dozen or more potential homesites, processes this information, and selects the most desirable site for its new residences" (Seeley, 2010, p. 199). Other sorts of complex decision-making that colonies engage include foraging, brood care, and dynamic developmental responses to shifts in ambient environments.

[8]There is also research indicating that feral honey bee hives demonstrate greater resilience to some pests than managed colonies (Seeley, 2010).

[9]There have also been suggestions that part of the hysteria about the "killer" nature of so-called "Africanized" honeybees can barely conceal underlying racist anxieties of some White Americans (Tsing, 1995).

livestock—along with the "meatification" of diets this enables (Weis, 2013)—constitutes a major impediment to prospects for ecological restoration (Crist, Mora, & Engelman, 2017; Machovina, Feeley, & Ripple, 2015).

The expansion of vast seed crop monocultures has contributed to the loss of forest, grassland, and wetland habitats for native pollinator populations, as well as greatly diminishing connectivity between habitat patches. Seed crop monocultures themselves represent an impoverished food supply, as many bees and other pollinators will not or only rarely collect pollen and nectar supply from these crops (with the notable exception of canola), and hybrid or genetically engineered (GE) crops have much different nutrient profiles than traditional landraces. Further, recurring cycles of mechanized tillage, compaction, and the decline of fallowing land reduce the pithy or hollow stems some native bees need for their nests and interferes with ground-nesting solitary bees as well as bumble bees (Kim, Williams, & Kreman, 2006). The reduced food supply on monocultures is made worse by the widespread reduction of hedge rows and other potential bee habitat on their margins, as competitive pressures drive industrial farmers to cultivate right up to the property edge.[10]

Finally, there is compelling evidence that pollinator populations are adversely affected by the pesticide override discussed in the following section. Insecticides can never wholly discriminate between "target" and "nontarget" species and pose unresolved risks of bioaccumulation. Herbicides eliminate many wildflowers that are full of nectar and pollen, some of which have synergistic relationships with native bees, and this loss may be one of the main causes of poor nutrition in honeybees and native bee decline (Dance, Botias, & Goulson, 2017; Roger, Michez, Wattiez, Sheridan, & Vanderplanck, 2017; Schmel, Teal, Frazier, & Grozinger, 2014).

5 | THE PESTICIDE OVERRIDE

The expansion of insect, weed, and fungus threats is a fundamental biophysical contradiction of industrial monocultures, resulting from the loss of natural controls, the widening definition of undesirable species, and the heightened ability of pests to spread in biologically simplified and standardized landscapes. Pesticides are, in turn, a fundamental override in industrial agriculture that epitomize the narrow, short-term horizons at work in organizing productive environments, as applied biochemistry is utilized by capital to contain these problems. But pesticides never simply evade nontarget species and, as has long been established, instead tend to persist and bioaccumulate in surrounding ecosystems (Carson, 1962; Pisa et al., 2015; Smalling et al., 2015), with a wide range of adverse ecological impacts—including for pollinators. Insecticides are directly implicated in some pollinator mortality, while herbicides augment the damage to ground habitats and pithy stems from tillage and compaction monoculture landscapes, further reducing the forage available to bees.

The political economic compulsion to find ways to override systemic problems simultaneously reinforces and benefits from the dominant ontology of entomological research and the experimental pressure to strictly control variables to determine causality (Suryanarayanan, 2015, 2016 Suryanarayanan & Kleinman, 2016). Although scientists now increasingly recognize the multifactorial and interactive character of honeybee health problems (David et al., 2016; Sgolastra et al., 2017), this still tends to be ignored in experimental practices that typically seek to isolate the effects of individual factors on bee population decline. The dominance of unifactorial studies is not only because interactional studies are harder to implement but also stems from the social organization of entomology in the United States, which developed as a scientific profession in the late-19th and 20th centuries hand-in-hand with the increasing insecticide development and proliferating use that was central to agricultural industrialization (Palladino, 1996; Suryanarayanan & Kleinman, 2016).

Entomologists in the U.S. Department of Agriculture, land-grant universities, and later on agrochemical companies developed *epistemic forms*—meaning experimental approaches, methods, measures, and interpretation styles—

[10]This has led to growing calls to re-establish hedge rows and uncultivated corridors within landscapes of industrial agriculture, or "pollinator pathways," which might have some role supporting pollinator populations but also risk diminishing the scope of changes that are necessary.

that were geared toward identifying insecticidal chemicals whose efficacy was evaluated based on relatively short-term time frames, lethal dosages, and ease-of-applications required to kill "target" pest insects (Suryanarayanan & Kleinman, 2013). A crucial flipside to what these epistemic forms emphasize is what they underemphasize: the possibilities of chronic, interactive, and sublethal effects that insecticides could have on "nontarget" species such as bees. Subsequent studies by U.S. entomologists to assess the effects of insecticides on "nontarget" honeybees relied on the very same epistemic forms that were developed to kill insect pests. The strong institutional ties between the field of entomology, especially in regard to honeybee health, and industrial agriculture has meant that entomologists' research agendas to understand and reduce the increasingly evident negative ecological effects of insecticides have often been placed in the service of the dominant path: Rather than seeking to resolve the root biophysical contradiction, many have helped develop new classes of insecticides intended to "reduce risks" by better targeting pests, as was the initial promise of the class of insecticides known as neonicotinoids.

Neonicotinoids are both systemic and persistent, killing insects by disrupting the function of their nervous systems, and are most commonly applied via coated seeds. Bayer CropScience is the principal manufacturer of neonicotinoids, with a few other significant players, including Syngenta (now part of ChemChina). Neonicotinoid usage became widespread from the mid-1990s onwards, first in North America and Europe, far before their long-term effects on bees and other wildlife could possibly be understood.[11] Neonicotinoid use is especially widespread on grain and oilseed crops. In the province of Ontario, for example, 99% of corn seeds and 60% of soybean seeds were infused with neonicotinoids before the implementation of a partial ban in 2017 (Ontario, Government of, 2017). While all insecticides have the potential to harm bees, the neonicotinoid class of pesticides is particular concerning because they are both systemic and persistent, finding their way into soil, wildflowers (David et al., 2016; Mogren & Lundgren, 2016), and waterways, with the potential to bioaccumulate (Krupke, Hunt, Eitzer, Andino, & Given, 2012) and negatively affect bee behaviour and health (European Food Safety Authority, 2016a; Goulson, 2013; Fairbrother, Purdy, Anderson, & Fell, 2014). The evidence of these impacts has led to pressure for moratoria in some places, most notably the EU, as discussed below. Further, recent studies have shown that neonicotinoids are even more dangerous to nontarget insects such as bees when they work synergistically with fungicides (Sgolastra et al., 2017), and there is growing evidence that herbicides—including widely used glyphosate—directly harm bees, in addition to indirectly affecting them by killing wildflowers (Abraham et al., 2018; Seide, Bernardes, Pereira, & Lima, 2018). Even when pesticide exposure is at sublethal levels, toxins can compromise bees' immune systems, making them more vulnerable to pests and pathogens and therefore factoring into the increasing use of miticides and antibiotics in beekeeping (an important part of the contradiction-override dialectic in large-scale beekeeping we develop in a subsequent section).

The pesticide override is also deeply intertwined with the development of genetically engineered (GE) crop varieties. While GE crops were initially touted as a means to achieve yield gains above those of hybridized high yield varieties (HYVs), over time, GE advocacy has increasingly focused on pest management, either by establishing defences in the biology of the crop itself (*Bt* varieties), building tolerance for a specific pesticide, or a combination of these traits (Klümper & Qaim, 2014).[12] The interlocking nature of GE and pesticide development is clearly illustrated in the engineering of crop varieties to be "tolerant" of Monsanto's already popular broad spectrum glyphosate herbicide, *Roundup*, which have expanded quickly since the 1990s. In both the United States and Canada, the large majority of corn, soybean, and canola land area is planted with GE seeds, led by *Roundup Ready* varieties.

There are a number of reasons to be wary of the claim that GE varieties reduce exposure to pesticides and the related suggestion that they are therefore better for—or at least less damaging to—pollinator populations (Mannion & Morse, 2012). First, GE crops are widely treated with neonicotinoid insecticides (as well as fungicides). Second, there is growing evidence that GE-specific pest protection (i.e., *Bt* varieties and the proliferation of directly

[11] In this, they also reflect an utter abandonment of the precautionary principle and the "regulatory capture" of corporations over the regulatory process (Altieri, 2004; Drucker, 2015).

[12] The focus on pest protection has led to a reorientation of claims about yields: Rather than increasing intrinsic yields, GE crops are promoted as a way of minimizing losses to insects, weeds, and fungus.

related chemicals like glyphosate) pose distinctive long-term risks to bees (Seide et al., 2018) and for emerging forms of biological resistance (Ávila Vázquez, Difilippo, MacLean, Maturano, & Etchegoyen, 2018; Beilin & Suryanarayan, 2017; Gilbert, 2013).[13] Third, the great majority of GE cropland is devoted to feed for industrial livestock operations, which wastes large amounts of useable nutrition and necessarily expands the amount of land that must be cultivated (and sprayed) (Weis, 2013). Fourth, there is strong evidence that organic crops can have comparable yields with both GE and HYV crops which, along with the inefficiency of cycling feed crops through animals, further dispels the land sparing potential of input-intensive monocultures (Badgley et al., 2007; Koohafkan, Altieri, & Holt Gimenez, 2012; Seufert, Ramankutty, & Foley, 2012). In sum, while GE varieties might be conceived as a partial override for *both* pest problems themselves and the ensuing problems with pesticides, they also complicate these contradictions in ways that adversely affect pollinator health.

6 | POLLINATION AS OVERRIDE

At the same time as pollination is affected by the pesticide override, it can also be seen to have been transformed in a way such that it is itself now a crucial though widely underappreciated override for industrial agriculture. That is, the expanding scale of production in certain crops has amplified the demand for pollination beyond the capacity of small-scale local beekeepers and native bees and other pollinators, especially with the aforenoted damage to habitats. This necessitated vastly greater scales of beekeeping and periodically hauling bees around at key junctures in the crop-growing cycle. The almond crop in California provides one of the most striking examples of honeybee pollination as biological override. Californian almonds represent over 80% of total world production (Almond Board of California, 2015), and this production is one of the largest pollinator-dependent systems in the world. Between 1996 and 2019 alone, the total acreage devoted to almonds in California more than doubled, from 428,000 to 1,170,000 acres of bearing fruit trees (National Agriculture Statistics Service, 2019), and total almond production quadrupled, increasing from 510 to 2,140 million pounds. Every February, the majority of all migratory beekeepers in the United States converge upon California almond orchards for the spring bloom, which requires approximately 2 million bee colonies, or over 80% of the total U.S. "stock" of bees in commercial pollinator services, and in 2012, the fees paid for pollination services for Californian almonds amounted to US$292.5 million, which was 44% of the total pollination service revenue in the United States that year (USDA, 2017; Bond, Plattner, & Hunt, 2014; van Engelsdorp & Meixner, 2010).

This is a dramatic departure from the free gift of pollination that prevailed throughout most of agrarian history. With the biological simplification and standardization of landscapes, pollination has increasingly been transformed into a commodified relation—a service that must be produced (in the sense of tending and transporting hives) and purchased. Commercial pollination services centre on honeybees and involve shipping bee colonies over much greater distances than could occur naturally, sometimes even on a continental scale. One estimate is that dependence on honeybee pollination more than doubled in the space of just a few decades (van Engelsdorp & Meixner, 2010), with the highest growth in pollinator-dependent crops between 1961 and 2012 occurring in China, Algeria, Argentina, Greece, and Libya (Potts et al., 2016). While honeybees predominate, some other bees are also commercially managed, including species of bumble bees, leafcutter bees, and mason bees. For instance, bumble bees are highly effective pollinators for certain crops (e.g., their ability to "buzz" pollinate is well-suited to tomatoes), and in the United States and Canada, they are widely used in large greenhouses—with some species like the Common Eastern Bumblebee (*Bombus impatiens*) that are native to the eastern United States and Canada and some species imported from Europe.

[13]Gilbert (2013) shows that while GE-crop production may involve less pesticides than conventional HYVs during the initial planting period, the proliferation of herbicide-resistant weeds such as Palmer Amaranth has already reversed this dynamic in many places and can be expected to reverse it soon in others.

The United States provides an extreme illustration of the rising distance that some pollination services move, as it is now common for commercial beekeepers there to follow different crop cycles in shipping bees from the East Coast to the West Coast and from the Midwest to the Southeast (see Figure 3). Together with almond production, which involves by far the largest pollination service payments, other commonly pollinated crops in the United States include canola, sunflowers, grapes, and apples. The transport trucking of bees reflects another contradiction associated with the biological simplification and standardization of landscapes: the need to move inputs and outputs across greater distances. This must be overridden with external energy inputs, comprising yet another element of the fossil energy dependence and GHG emissions of industrial agriculture.

Although the health outcomes from shipping colonies from one monoculture crop to another is an understudied subject, there is some indication that movement and the lack of diversified forage have detrimental impacts. One recent study found that the bees in migratory colonies had shorter lifespans and showed increased evidence of nutritional deficiencies and oxidative stress (Simone-Finstrom et al., 2016). Research conducted by the Bee Informed Partnership (BIP) over the past decade also gives some indication that long-distance migration might be contributing to the losses of honeybee colonies in the United States. Statistics show that summer losses of honeybee colonies are most pronounced among commercial beekeepers, whereas in the winter, backyard beekeepers have the highest losses. They speculate that this pattern could result from the increased pesticide exposure commercial honeybee

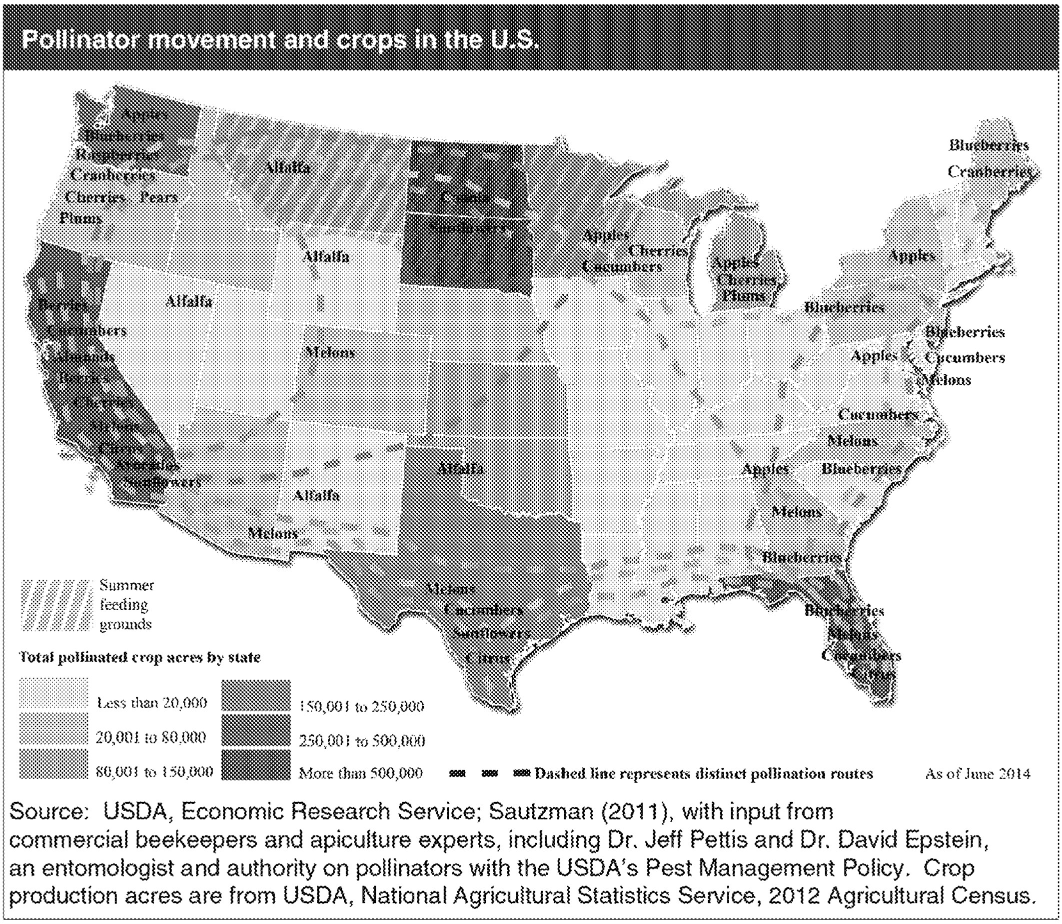

FIGURE 3 Major pollinator movements and crops in the United States. *Source*: Bond et al. (2014, p. 3)

colonies face during pollination and the transmission of diseases as a result of migration, though there are limits to the quality of this data (Kulhanek et al., 2017; Seitz et al., 2016).[14]

In both the United States and Canada, the growth of a sizable industry in pollination services has been entwined with a marked bifurcation of beekeeping (Constance, Choi, & Lyke-Ho-Gland, 2008). Small-scale operations have been steadily displaced by large commercial operations, though some medium-scale commercial operations with colonies between 50 and 500 still persist, with revenues centred on selling honey augmented by some side-pollination over short distances. The bifurcation of beekeeping also bears some relation to a more generalized pattern within agriculture in the United States and Canada, as there has been a marked decline in small-scale farmers who were historically more inclined to maintain small apiaries than large industrial farmers. Another factor is that large operations have been better able to cope with periodic honeybee colony losses from viruses, parasites (most notably the Varroa mite), and overwintering mortality than small-scale beekeepers, by turning to chemical treatments or by rapidly expanding the number of managed colonies in the wake of a crash. Small-scale beekeepers in the United States and Canada have also been hurt by increasing imports of honey and beeswax from other parts of the world (van Engelsdorp & Meixner, 2010).[15]

To the extent that people are aware of large-scale commercial beekeeping, it is likely most would assume it revolves around selling honey and other bee-created products. The reality, however, is that few beekeepers can make a livelihood out of honey and beeswax sales, especially in industrialized countries like the United States and Canada, and the primary source of profit for large beekeeping operations is through selling pollination services for monocultured crops. Yet because the appropriation of honey and other bee products remains a secondary source of profits in these operations, there is a need to provide a stable food supply for the large colonies, a challenge that is obviously compounded by the cycles of trucking. In the United States, one response of many large-scale, long-distance shipping operations was to stop in the Upper Midwestern plains of the Dakotas—usually on the way back from the west coast—to let their bees recover on wildflowers, while also making honey, but these practices have diminished as wildflowers have been increasingly replaced with corn, soy, and wheat monocultures (Durant, 2019). This feed contradiction (in the sense that there are times where these hives lack sufficient food sources) is now regularly met with sugar syrup and "pollen patties" that are often composed of combinations of high fructose corn syrup and soybean oil.

The expansion of large-scale commercial beekeeping and pollination services has been characterized as the *apis-industrial-complex*, which is helpful in suggesting the web of commodity flows both as input costs (hives, antibiotics, pesticides, feed, new colonies and queens, and trucking) and revenue streams (pollination services and bee products) (Nimmo, 2015). It also effectively signals how integral large-scale commercial beekeeping has become for industrial monocultures, and some parallels with industrial livestock production. Like industrial monoculture and livestock production, pollination services hinge on an unsustainable chain of relationships that increasingly require a series of more and more sophisticated overrides. Taken together, the apis-industrial-complex can be seen as a profound betrayal of the age-old interspecies relation between humans and bees. In this new relation, humans continue to take the products of the hive—and in fact may take more than ever, leaving bees with pollen patties and sugar syrup. But the diversified forage and habitat previously provided on diverse farms is long now gone, replaced with oceans of monoculture, heavily treated with pesticides. Native bees may fare even worse, as they not only lack diversified forage but their habitats have been greatly diminished.

Due to the vast differences in scale, most honeybee colonies in the United States are managed by commercial beekeepers (operations with 500 or more colonies), while most individuals involved in beekeeping are considered "backyard beekeepers" (with 50 or fewer colonies).[16] For backyard operations, renting pollination services and the

[14]Although the BIP conducts research on summer colony losses, the information provided by beekeepers is voluntary, and there are clear limits to self-reported colony loss surveys as beekeepers may have highly heterogeneous understandings of the complexity of factors that affect honeybee health.
[15]Australia has "clean wax," as honeybees there have few parasites and tend to be less treated with chemicals. Some beekeepers see the importation of much cheaper, partly adulterated honey from China as a growing threat.
[16]This definition follows that given by BIP. Sideline beekeepers (with 51–500 colonies) sit in the middle, which is being hollowed out (Kulhanek et al., 2017).

products of the hive might provide an additional source of income but could not constitute a livelihood, and even where these interspecies relations have been partly commodified, they can still sometimes resemble something close to mutually beneficial, a subject we will return to in the conclusion.

7 | OVERRIDING CONTRADICTIONS WITHIN COMMERCIAL BEEKEEPING OPERATIONS

As with animals in industrial livestock production, bees in large-scale commercial operations are susceptible to a range of chronic health problems. There is growing evidence in entomological research that the unnatural simplification of honeybee diets (i.e., and loss of diversity of nectar, pollen, and propolis), the reduced genetic diversity in honeybee populations, and the proliferation of chemicals such as neonicotinoids (Tesovnik et al., 2017) and fungicides are major factors weakening immune systems of bees (Brandt, Gorenfloe, Reinhold, Meixner, & Buchler, 2016) and reducing their ability to fight off viruses and parasites (Aufauvre et al., 2014; Brosi, Delaplane, Boots, & De Roode, 2017; Pettis, VanEngelsdorp, Johnson, & Dively, 2012). Along with unnatural diets, commercial beekeeping disrupts the social organization within hives through the frequent long-distance movement of colonies across bioregions—which is layered onto older, pre-industrial manipulations like the artificial replacement of queens and interventions to supress swarming, which is otherwise a natural part of a colony's lifecycle and tied to virus and parasite resistance. Although understudied, this disruption can potentially happen in several ways. Mobile commercial beekeeping enterprises tend to replace the queen (to "re-queen") instead of allowing the worker bees to replace her with a new queen. New queens, who also often move across great distances, are replaced with an already mated queen. The replacement queen is not from the same colony, breaking the lineage of the colony, which is potentially problematic if the colony has been parasite-resistant.

Frequent movement of hives over vast distances can result in the loss of some foraging bees as they use various markers to identify which hive is theirs, including markers in the landscape such as nearby vegetation. This movement can also contribute to the drifting of worker and drone bees to nearby hives, which, as stated above, is implicated in the spread of parasites between colonies. Depending on the time of day bees are moved, foraging bees who have not returned to the hive for the night may be left behind. Worker bees have relatively short lifespans, and the time it takes to move the hives across landscapes may prevent them from playing crucial roles within the hive. In contrast to a popular image of the queen controlling the colony, complex decisions about swarming, foraging, and replacing the queen are made by the worker bees as a whole, based on nuanced forms of communication (including the famed "bee dance") and subtle changes in pheromones. While the limits of scientific research urge caution here, it is plausible that these radical changes in the social organization of bees—especially when considered together—may be disrupting the complex decision-making of colonies and, to the extent they are causing stress for bees, factor in declining health conditions. In this regard, recent cognitive research demonstrating that bees possess some remarkable problem-solving capacities (Barracchi, Vasas, Jamshed Iqbal, & Alem, 2018) may yield future insights into decision-making (Seeley & Visscher, 2003) and stress-inducing changes,[17] a point we return to later.

Although there are entomological debates about the extent to which rising commercially managed honeybee populations directly *cause* falling native bee populations (Mallinger, Gaines-Day, & Gratton, 2017), there is growing evidence to indicate that the long-distance trucking of bee colonies for pollination is an important factor in the spread of viruses and parasites affecting both. For instance, some viruses and parasites have become endemic among honeybee populations and have spread to bumble bees, which, in North America, are the only other truly social bees. The escape of some commercially raised bumble bees from North American greenhouses is another explanation

[17]Researchers have investigated various aspects of bee behaviour, cognition, and learning (Behrends & Scheiner, 2009; Loukola, Perry, Coscos, & Chittka, 2017), especially among honeybees and bumble bees. Research has shown that bees engage in social learning, that they have memories (Reinhard, 2015), even to the extent of having false memories based on memory fragments (Reinhard, Srinivasan, & Zhang, 2006); that they can be pessimistic based on previous experiences; and that they engage in nuanced forms of communication and decision-making.

given for the spread of some viruses to wild bumble bees (Colla, Otterstatter, Gegear, & Thomson, 2006). Flowers, which are shared hubs for a variety of insect pollinators, are crucial sites for the exchange and transmission of microbial pathogens across species lines. Drifting behaviour of honeybees, where incoming foragers drift into a different hive from which they exited, is another major source of disease and mite transmission. Drifting is significantly compounded where pollination services are deployed in landscapes dominated by large monocultures, such as California's almond orchards, as millions of hives get situated in close proximity. A recent study found that a significant number of drone bees drift to neighbouring hives, a concern because drone larvae are more susceptible to Varroa mite infestation (Seeley & Smith, 2015).

Research also suggests that some bee management practices that create convenience for beekeepers may be harming the ability of bees to develop behaviours that foster parasite resistance. For example, studies have found that propolis, a sticky substance made from resin of trees and used by bees as a glue, may also help to build immunity in bees when ingested (Simone-Finstrom, Borba, Wilson, & Spivak, 2017; Simone-Finstrom & Spivak, 2012). Propolis is often removed by beekeepers to make it easier to open the hive and move frames. Another routine practice of beekeepers is to stop swarming, in spite of mounting evidence that swarming is a natural behaviour used to stop the lifecycle of various bee pathogens and parasites as it interrupts brood development and can interrupt mite lifecycle (Loftus, Smith, & Seeley, 2016; Royce, Rossignol, Burgett, & Stringer, 1991).

In sum, there are many reasons to suggest that the nature of production—biologically standardized landscapes, pervasive pesticides, unprecedented concentrations, and movement of hives—is inducing a series of chronic health problems. But again, much as with industrial livestock production, the imperatives of increasing scale and the nature of technoscientific reductionism together narrow how these contradictions are assessed, with this knowledge then applied to establish another set of biophysical overrides (Weis, 2013). The similarities between some key overrides in commercial beekeeping and industrial livestock production are striking, especially the need to provide external sources of feed and the increasing use of antibiotics and other chemicals. Today, the use of antibiotics (commonly integrated into the sugar syrup or high fructose corn syrup fed to bees), fungicides, and miticides are systemic in commercial beekeeping operations, in the sense that they are deployed in a chronic way to contain generalized risks rather than in response to a specific disease or pest outbreak. These overrides might or might not contain problems indefinitely, but the long-term response is far from straightforward and poses risks of declining effectiveness and increasingly hardy diseases and pests developing in response.

8 | ACCELERATING CONTRADICTIONS: POLLINATION CRISES AND RESPONSES

As indicated earlier, the dialectic of biophysical contradictions and overrides is such that root problems are never resolved while the perpetual use of overrides establishes deeper or unforeseen problems in the long run. Biophysical contradictions can be seen to be accelerating as they become more difficult and expensive to manage, individually or collectively, and make the whole system as it is configured untenable. There are a number of indications the contradictions of pollination associated with industrial agriculture can now be seen to be accelerating.

Beekeepers began to be concerned about the effects of neonicotinoid pesticides on honeybees after a spike in the loss of honeybee colonies in the United States over the winter of 2006 (Fairbrother et al., 2014) and severe honeybee losses in Canada and Europe in subsequent years. While the occurrence of CCD has since declined, winter losses of honeybee colonies have remained worryingly high, and unexpected summer losses have emerged as new concerns. As indicated, definitive causation is extremely hard to determine, but emerging research points to multiple factors at play. Growing concerns about CCD contributed to research on the effects of neonicotinoid pesticides on bees. Although bees rarely visit corn and soy, the most widespread crops it is applied to, they do regularly pollinate canola as noted, and there have been some reports of immediate neonicotinoid poisonings of bee colonies (Fairbrother et al., 2014). Scientific research suggests that the biggest threat from neonicotinoids is not from direct exposure but from the cumulative effects of sublethal exposure, as researchers have demonstrated that this can adversely affect the learning, foraging, immune system functioning, and homing abilities of both honeybees and bumble bees (Brandt et al., 2016; Goulson, 2013). As with other pesticides, neonicotinoids drift beyond fields and persist in soil and waterways, and neonicotinoid-positive pollen has been found in beehives from nontarget plants (Tsvetkov et al., 2017). Research suggests that toxic amounts of pesticide exposure can be reached in the field within days or weeks and that even low levels of exposure may cause a reduction in hive fitness (Woodcock et al., 2017). It is harder to collect data on the effects of neonicotinoids on wild, solitary bees, and hence, these impacts are less clear, though there is some indication that wild bees tend to be more vulnerable than honeybees to the effects of pesticides and other environmental stresses such as climate change and deforestation (Goulson, 2013; Suryanarayanan & Beilin, forthcoming), with some entomologists suggesting that the complexity of honeybee colonies may help to buffer them to a limited extent from the negative effects of pesticides (Suryanarayanan, 2015).

Yet even as evidence mounts that neonicotinoids accumulate in pollen and nectar to an extent that can disrupt the nervous systems of bees, there is a difficult burden of proof to disentangle and implicate any one cause. For instance, in a U.S.-based study on the wax and pollen of honeybee hives, researchers detected the presence of at least one pesticide and 120 other agrochemicals, which clearly points to the complexity of chronic exposure and the challenge of unpacking it (David et al., 2016). Another recent study on honeybee exposure to neonicotinoids from corn crops found that "acute toxicity of neonicotinoids to honeybees doubles in the presence of a commonly encountered fungicide" (Tsvetkov et al., 2017, p. 1395). Now, consider the challenge of isolating the effects of neonicotinoids from a wider range of factors bearing on bee health: varying exposures to an array of insecticides; the widespread use of herbicides (with expansive damage to nesting and food supplies); extensive habitat loss and fragmentation; chronic antibiotic, fungicide, and miticide use in bee colonies; the changing interactions between unmanaged native bees and semi-domesticated bees (including impacts from the long-distance translocation of colonies); and the ecological variations wrought by climate change with unpredictable new parameters in store. In short, major changes are unfolding at a range of scales and are interwoven in complex ways.

Seed and chemical corporations have exerted a great deal of influence over regulatory policy using complexity to sow doubt to lobby against regulations, following a familiar playbook to the one used to stifle other forms of environmental regulation including responses to climate change (Oreskes & Conway, 2010). A central feature of this has been their use of long-established research norms about what counts as conclusive evidence of harm, exemplified in Bayer's responses to the debate over the extent to which neonicotinoids are implicated in declining bee health (Suryanarayanan & Kleinman, 2016). In addition to backroom lobbying and over public relations campaigns, seed and chemical corporations have funnelled resources through deceptive-looking front groups, such as American Council on Science and Health, American Farmers for the Advancement and Conservation of Technology, America's Farmers (Bayer Fund), and Alliance for Food and Farming. They have also forged alliances with some large-scale farmer (e.g., Grain Farmers of Ontario and Canadian Federation of Agriculture) and beekeeper associations (e.g., Canadian Honey Council) that are possible where members have internalized the logic of industrialization.

In spite of the strength of this opposition, the weight of scientific evidence showing the harm caused by neonicotinoids to bees and other insects has increased pressures for regulation, abetted by effective public education campaigns by several environmental organizations. The most notable case was the EU's temporary moratorium on three widely used neonicotinoids (imidacloprid, clothianidin, and thiamethoxam) established in 2013 with the support of environmentalists, beekeepers, and many scientists, despite the intense opposition of agrochemical corporations and industrial agricultural lobbyists (Cressey, 2017). The vote on whether to extend the moratorium was initially scheduled for December 2017 but got delayed awaiting a report by the European Food and Safety Agency (EFSA), which was ultimately released in February 2018 with the firm conclusion that "most uses of neonicotinoid pesticides represent a risk to wild bees and honeybees" (European Food Safety Authority, 2018). Following this report, the European Commission proposed a ban on the outdoor use of the same three neonicotinoid pesticides (they can still be used in some greenhouse operations), which was endorsed by member states in April 2018 (European Commission, 2018).

The government of Canada is also currently considering a nation-wide ban against the same three neonicotinoids, following on the partial ban of up to 80% of their use in the province of Ontario in 2016 that came into full effect in the 2017 growing season. Given both the scale of these markets and the precedent, dominant seed and chemical corporations will undoubtedly continue to mount legal challenges to the rulings in Europe and Ontario, just as they will surely oppose any new bans elsewhere. In the face of this pressure, scientists, activists, and governments will need to be extremely cognizant not only of the science but also of the politics of knowledge, and there are clear indications that many scientists are bracing for this challenge, as evident in a June 2018 statement in *Science* in which 233 scientists called for the global restriction of neonicotinoid pesticides (Goulson, 2018).

9 | MOBILIZABLE SUBJECTS: BEES IN ANTI-SYSTEMIC MOVEMENTS

The framework of biophysical contradictions and overrides existing in a dialectical relation helps make sense of the interrelations between the ongoing transformation of pollination into a commercial service, the role of industrial agriculture in the decline of pollinators, and the growing challenges this poses for the future. As the biophysical contradictions of pollination accelerate, an urgent search for answers and responses is unfolding, and this need not lead down a dystopian course.[18]

The growing popular awareness and concern about bees presents openings for teaching and movement building, in that they necessitate serious conversations about an inherently destructive way of organizing nature and point towards the need for radical changes rather than simple reforms (as pressing as certain precautionary regulations might be, like moratoria on a particular class of insect-killing chemicals). To convey this to a wide audience will require a broad mobilization that could involve alliances between scientists, beekeepers, native bee advocates, environmentalists, and farmers committed to the flourishing of bees. While recognizing the complexity of definitive causation, these movements need to draw clear lines between the precarious health of bees and the simultaneous *force and fragility* of industrial monocultures and commercial pollination services. They also need to be attentive to the constellations of power that surround seeds and pesticides that are bent on obscuring the connections between biophysical problems and overrides. An important aspect of this will be to counter the small number of very powerful seed and agrochemical corporations that are trying to sow doubt about the mounting empirical evidence informing struggles to restrict or ban neonicotinoids and other pesticides (Ellis, 2018).

It is also crucial to draw links between the forces destroying the habitat and foraging areas of both managed and wild bees and the precarity of human communities that retain and directly rely upon these interspecies relations. As Potts et al. (2016) emphasize, fallout of the pollinator crisis will not affect all farmers evenly, as many small farmers around the world produce crops (e.g., cacao, coffee, nuts, and fruits) that depend on animal pollination, and as the "free gift" of pollination declines, small farmers will obviously tend to be less able to afford commercial pollination services than large-holders. Furthermore, many bee-pollinated crops contain essential micronutrients, such as Vitamin A and folic acid, that are frequently in scarce supply for food insecure people, which means that continuing pollinator declines could well contribute to heightened nutrient deficiencies among poor people. The significant place of bees in various cultures around the world, both functionally and spiritually, could also emerge as a mechanism of resistance, to the extent that the threat posed to bees by industrial agriculture can be effectively understood as a threat to cultures.[19]

Beekeepers have been at the forefront of raising the alarm about the health of bees based on their intimate knowledge of their honeybee colonies. In a study on beekeepers' knowledges, Maderson and Wynne-Jones (2016) stress the importance of mindful observation and sensual engagement in guiding beekeeping practices, arguing that

[18] Some particularly grim responses have included farmers hand-pollinating fruit blossoms en masse (Partap & Ya, 2012), attempts by engineers and computer scientists to create "Robo-bees" (Johnson, 2011), and attempts by scientists to genetically engineer mite-resistant bees (Schulte, Theilenberg, Muller-Borg, Gempe, & Beye, 2014).

[19] The resistance of Mayan beekeepers to pesticides and GE crops in Yucatan exemplifies this (Suryanarayanan & Beilin, forthcoming).

these practices help to shape traditional ecological knowledge about bee ecologies and health. Of course, not all beekeepers are activists, and to the extent that beekeepers continue to be embedded in industrial agricultural landscapes, they will continue to struggle with bees sickened by the contradictions and overrides discussed here. Nevertheless, it is constructive to consider how the intimate interspecies relations between beekeepers and bees, and the ability to deeply sense problems, might help inform and connect to wider struggles over the factors affecting bee health. One important front here is small-scale beekeepers and associations—which are working to enhance habitats in non-commodified ways, though many face growing pressure to adopt the practices of commercial beekeepers, such as feeding antibiotic-infused sugar syrup and using routine pesticide treatments. There is also a need to reflect on the often-heated debates between beekeepers who have conceded to commercial approaches and those who reject them (or remain "treatment-free"), and between native pollinator advocates and honeybee advocates (which frustratingly often sidesteps the centrality of industrial agriculture) and between small-scale and large-scale beekeepers.[20]

To think about the prospects of reinvigorating mutually beneficial interspecies relations in settings where they have been widely undermined starts with changing agricultural and bee management practices like stopping the trucking of honeybees across great distances (and between different bioregions) to pollinate monocultured crops, minimizing exposure to chemicals both within and outside the hive, and enhancing the diversity of food supplies. Ultimately, it also points towards allowing bees more autonomy over the lifecycle of their colony, as some beekeepers are aspiring to do, through practices such as allowing colonies to replace the queen and allowing bees to swarm, which, along with presenting particular conceptual challenges and opportunities,[21] problematizes the status of honeybees as commodities that are owned by an individual beekeeper. Although there are concerns about honeybees competing with native bees (Colla & MacIvor, 2016), there are also hopeful indications that all bees can flourish when given access to an abundance of forage (Herbertsson, Lindstrom, Rundlof, Bommarco, & Smith, 2016). Honeybees naturally move slowly across landscapes with swarming, and it is possible that small-scale beekeeping coupled with more polycultural agriculture could help to keep honeybee populations at a level that can co-exist with native bees.

Taking the agency of bees seriously also means considering ways in which bees themselves may resist certain aspects of the apis-industrial complex. Ground-breaking research is showing how social bees are sophisticated beings both as individuals and as colonies, capable of engaging in social learning, the cultural transmission of new or unusual skills, and complex problem-solving (Loukola et al., 2017; Alem et al., 2016), and regardless of whether one accepts the argument that the collective decision-making of bee colonies might be considered "democratic" (Seeley, 2010),[22] at some level, decisions to swarm or to establish a new queen can be seen as a rejection of the conditions faced by the colony. This bounded agency of bees—recalling their not completely domesticated status—can be nourished by beekeepers, as well as other activists seeking to confront the logic of industrial agriculture. The scaling-up of bee-keeping to the level of current average commercial beekeeping operations could be replaced with a scaling out of small-scale beekeepers. Scaling out small-scale beekeeping necessarily entails a disruption to the current trajectory of fewer beekeepers managing increasing numbers of colonies (in the thousands), to more beekeepers, each managing a smaller number of colonies. We are not suggesting a return to a romanticized agrarian past but the need to take steps towards an uncertain future, in which small-scale beekeepers are actively sharing low-tech and mindful

[20]In terms of parasite control, perhaps the most contentious issue between beekeepers relates to growing evidence that what might save a colony in the short-term (use of miticides, mass replacement of diseased colonies, etc.) may harm honeybees—and by extension native bees—in the long term. Debates that are also starting to heat up between large-scale commercial beekeepers. A good example of this is a hostile debate over neonicotinoids between the Ontario Beekeepers Association (OBA) and the Canadian Honey Council (of which the OBA is a member).

[21]Admittedly, the sight of a swarm can be upsetting and frightening to people, even though swarming bees are known to be gentle and to lack the defensiveness usually exhibited by honeybee colonies. Swarming presents a challenge to the possibilities for co-creation of urban spaces with bees and yet also presents an opportunity for people to witness and appreciate the agency and even autonomy of honeybees.

[22]Seeley (2010) argues that honeybee decision-making is so sophisticated that humans can learn from the democratic processes of a colony in the structure of our own group decision-making processes.

innovations with one another. Ideally, this would evolve as part of an alliance with agroecological farmers and allied food movements.

Another way in which the bounded agency of bees can be nourished is through the creation of spaces in both urban and rural areas, in which honey and native bees can forage and native bees can find appropriate habitats. This requires the development of gardening and farming practices that provide organic forage of a diversity of plants for all bees and that provide the snags, pithy stems, and dirt patches needed by native bees. It also means learning to live with bees and to respect them as co-creators of space that are essential to the healthy functioning of ecosystems, rather than as commodities with narrowly defined functions. This also means learning to accept decay and “messy” gardening, to live with plants considered weeds especially those that are native to the area, and to encourage people to plant polycultures at whatever scales they can.

While many people have a strong sense that there are sharp divisions between cities and the countryside, it is also possible to see this division as more malleable, porous, and culturally created. For instance, both native and honeybees do not pay attention to these human-created boundaries, foraging wherever there are abundant nectar and pollen producing flowers and finding habitat in any spaces that fulfil their needs, including in cities. Thus, efforts to enhance organic forage within cities, such as through the promotion of messy gardens and pollinator corridors, are some hopeful initiatives that not only help bee populations but can help more urban people to see and better understand how they are connected other species and food systems.

Industrial capitalist agriculture impoverishes landscapes in many ways, and the complexity of these problems present a range of organizing challenges and opportunities. We believe that well-designed education and outreach campaigns concerning the threats to bees and the dynamics of pollination can have a powerful role helping people appreciate the need to resist this destructive trajectory. This can also be entwined with a very hopeful counter-narrative, as efforts to foster mutually beneficial interspecies relations between people and bees are an important part of broader struggles to rebuild biodiverse landscapes of abundance. Clearly, small-scale beekeepers and agroecological farmers are central to this. It is also possible that the range of small but direct ways to contribute to improving relations with bees can mobilize many other people as active participants and thereby strengthen the basis of support for agroecological alternatives.

ORCID

Rebecca A. Ellis https://orcid.org/0000-0001-9557-9390

REFERENCES

Abraham, J., Benhotens, G. S., Krampah, I., Tagba, J., Amissah, C., & Abraham, J. D. (2018). Commercially formulated glyphosate can kill non-target pollinator bees under laboratory conditions. *Entomologica Experimentalis et Applictata*, *16*(8), 695–702.

Alem, S., Perry, C.J., Loukola, O.J., Ingraham, T., Sofia, E., & Chittka, L. (2016). Associative Mechanisms Allor For Social Leasing and Cultural Transmissions of String Pulling in an Insect. *PLOS Biology*, *14*(12). https://doi.org/10.1371/journal.pbio.1002564

Almond Board of California. (2015). *Almond Almanac 2015*. https://www.almonds.com/sites/default/files/content/attachments/2015_almanac.pdf

Altieri, M. (2004). *Genetic engineering in agriculture: The myths, environmental risks, and alternatives*. Oakland: Food First Books.

Aufauvre, J., Misme-Aucouturier, B., Vigues, B., Texier, C., Delbac, F., & Blot, N. (2014). Transcriptome analyses of the honeybee response to *Nosema ceranae* and insecticides. *PLoS ONE*, *9*, e91686. https://doi.org/10.1371/journal.pone.0091686

Ávila Vázquez, M., Difilippo, F. S., MacLean, B., Maturano, B., & Etchegoyen, A. (2018). Environmental protection environmental exposure to glyphosate and reproductive health impacts in agricultural population of Argentina. *Journal of Environmental Protection*, *9*, 241–253. https://doi.org/10.4236/jep.2018.93016

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Avilés-Vásquez, K., … Perfecto, I. (2007). Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems*, *22*(2), 86–108. https://doi.org/10.1017/S1742170507001640

Barracchi, D., Vasas, V., Jamshed Iqbal, S., & Alem, S. (2018). Foraging bumblebees use social cues more when the task is difficult. *Behavioral Ecology*, *29*(1), 186–192. https://doi.org/10.1093/beheco/arx143

Behrends, A., & Scheiner, R. (2009). Evidence for associative learning in newly emerged honey bees (*Apis mellifera*). *Animal Cognition*, *12*(2), 249–255. https://doi.org/10.1007/s10071-008-0187-7

Beilin, K., & Suryanarayan, S. (2017). The war between amaranth and soy: Interspecies resistance to transgenic soy agriculture in Argentina. *Environmental Humanities*, *9*(2), 204–229. https://doi.org/10.1215/22011919-4215211

Benzie, R. (2015). Ontario first in North America to curb bee-killing neonicotinoid pesticides. *Toronto Star*. Retreived from https://www.thestar.com/news/queenspark/2015/06/09/ontario-first-in-north-america-to-ban-bee-killing-neonicotinoid-pesticides.html

Berenstein, H. (2010). *Class Dynamics of Agrarian Change*. Winnipeg: Fernwood Publishing

Bond, J., Plattner, K., & Hunt, K. (2014). Fruit and tree nuts outlook: Economic insight. US pollination-services market. USDA Economic Research Service, FTS-357SA. Retreived from https://www.ers.usda.gov/webdocs/publications/37059/49131_special-article-september_-pollinator-service-market-4-.pdf?v=41911

Brandt, A., Gorenfloe, A., Reinhold, S., Meixner, M., & Buchler, R. (2016). The neonicotinoids thiacloprid, imidacloprid, and clothianidin affect the immunocompetence of honey bees (*Apis mellifera* L.). *Journal of Insect Physiology*, *85*, 40–47.

Brosi, B. J., Delaplane, K. S., Boots, M., & De Roode, J. C. (2017). Ecological and evolutionary approaches to managing honeybee disease. *Nature Ecology and Evolution*, *1*(9), 1250–1262. https://doi.org/10.1038/s41559-017-0246-z

Carrington, D. (2017). Europe poised for total ban on bee-harming pesticides. The Guardian. Retreived from https://www.theguardian.com/environment/2017/mar/23/europe-poised-for-total-ban-on-bee-harming-pesticides

Carson, R. (1962). *Silent Spring*. Boston: Houghton Mifflin.

Colla, S. R., & MacIvor, S. (2016). Questioning public perception, conservation policy, and recovery actions for honeybees in North America. *Conservation Biology*, *31*(55), 1202–1204.

Colla, S. R., Otterstatter, M. C., Gegear, R. J., & Thomson, J. D. (2006). Plight of the bumble bee: Pathogen spillover from commercial to wild populations. *Biological Conservation*, *129*(4), 461–467. https://doi.org/10.1016/j.biocon.2005.11.013

Constance, D., Choi, J., & Lyke-Ho-Gland, H. (2008). Conventionalization, bifurcation, and quality of life: Certified and non-certified organic farmers in Texas. *Southern Rural Sociology*, *23*(1), 208–234.

Crane, E. (1999). *The world history of beekeeping and honey hunting*. New York: Routledge.

Cressey, D. (2017). Neonics vs. bees. *Nature*, *551*(Nov), 156–158. https://doi.org/10.1038/551156a

Crist, E., Mora, C., & Engelman, R. (2017). The interaction of human population, food production, and biodiversity protection. *Science*, *356*(6335), 260–264. https://doi.org/10.1126/science.aal2011

Dance, C., Botias, C., & Goulson, D. (2017). The combined effects of a monotonous diet and exposure to thiamethoxam on the performance of bumblebee micro-colonies. *Ecotoxicology and Environmental Safety*, *139*, 194–201. https://doi.org/10.1016/j.ecoenv.2017.01.041

David, A., Botias, C., Abdul-Sada, A., Nicholls, E., Rotheray, E. L., Hill, E. M., & Goulson, D. (2016). Widespread contamination of wildflower and bee-collected pollen with complex mixtures of neonicotinoids and fungicides commonly applied to crops. *Environment International*, *88*(3), 169–178. https://doi.org/10.1016/j.envint.2015.12.011

Drucker, P. (2015). *Altered genes, twisted truth: How the venture to genetically engineer our food has subverted science, corrupted government, and systematically deceived the public*. Fairfield, IO: Clear River Press.

Durant, J. (2019). Where have all the flowers gone? Honey bee declines and exclusions from floral resources. *Journal of Rural Studies*, *65*(1), 161–171. https://doi.org/10.1016/j.jrurstud.2018.10.007

Ellis, R. (2018). Save the bees? Agrochemical Corporations and the Debate Over Neonicotinoids in Ontario. *Capitalism Nature Socialism*, *30*, 104–122. https://doi.org/10.1080/10455752.2018.1494748

European Commission. (2018). Neonicotinoids. Retrieved from https://ec.europa.eu/food/plant/pesticides/approval_active_substances/approval_renewal/neonicotinoids_en

European Food Safety Authority. (2016a). Pesticides and bees: EFSA to update neonicotinoid assessments. Retreived from https://www.efsa.europa.eu/en/press/news/160111

European Food Safety Authority. (2018). Neonicotinoids: Risks to bees confirmed. Retrieved from https://www.efsa.europa.eu/en/press/news/180228

Fairbrother, A., Purdy, J., Anderson, T., & Fell, R. (2014). Risk of neonicotinoid insecticides to honeybees. *Environmental Toxicology and Chemistry*, *33*(4), 719–731. https://doi.org/10.1002/etc.2527

Food and Agriculture Organization. (2018). *The Pollination of Cultivated Plants: A Compendium for Practitioners*, Vol 1. D. Roubik (ed.). http://www.fao.org/3/i9201en/I9201EN.pdf

Gilbert, N. (2013). A hard look at GM crops. *Nature*, *497*(2 May), 24–26. https://doi.org/10.1038/497024a

Goulson, D. (2013). Neonicotinoids and bees: What's all the buzz? *Significance*, *10*(3), 6–11. https://doi.org/10.1111/j.1740-9713.2013.00658.x

Goulson, D. (2018). Call to restrict neonicotinoids. *Science*, *360*(6392), 973. https://doi.org/10.1126/science.aau0432

Goulson, D., Nicholls, E., Botias, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, *347*(6229). https://doi.org/10.1126/science.1255957
Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., … de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE*, *12*(10), e0185809. https://doi.org/10.1371/journal.pone.0185809
Herbertsson, L., Lindstrom, S. A. M., Rundlof, M., Bommarco, R., & Smith, H. G. (2016). Competition between managed honeybees and wild bumblebees depends on landscape context. *Basic and Applied Ecology.*, *17*(7), 609–616. https://doi.org/10.1016/j.baae.2016.05.001
Johnson, E. R. (2011). Bees. In: *Reanimating bios: Biomimetic science and empire.* University of Minnesota Ph.D. Dissertation, 127-165. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/117375
Kim, J., Williams, N., & Kreman, C. (2006). Effects of cultivation and proximity to natural habitat on ground-nesting native bees in California sunflower fields. *Journal of the Kansas Entomological Society*, *79*(4), 309–320. https://doi.org/10.2317/0507.11.1
Kimbrell, A. (Ed.) (2002). *The fatal harvest reader: The tragedy of industrial agriculture*. Washington, DC: Island Press.
Klümper, W., & Qaim, M. (2014). A meta-analysis of the impacts of genetically modified crops. *PLoS ONE*, *9*(11), e111629. https://doi.org/10.1371/journal.pone.0111629
Koohafkan, P., Altieri, M. A., & Holt Gimenez, E. (2012). Green agriculture: Foundations for biodiverse, resilient and productive agricultural systems. *International Journal of Agricultural Sustainability*, *10*(1), 61–75. https://doi.org/10.1080/14735903.2011.610206
Krupke, C. H., Hunt, G. J., Eitzer, B. D., Andino, G., & Given, K. (2012). Multiple routes of pesticide exposure for honey bees living near agricultural fields. *PLoS ONE*, *7*(1). https://doi.org/10.1371/journal.pone.0029268
Kulhanek, K., Steinhauer, N., Rennich, K., Caron, D. M., Sagili, R. R., Pettis, J. S., … van Engelsdorp, D. (2017). A national survey of managed honey bee 2015–2016 annual colony losses in the USA. *Journal of Apicultural Research*, *56*(4), 328–340. https://doi.org/10.1080/00218839.2017.1344496
Lin, W., McBroome, J., Rehman, M., & Johnson, B. R. (2018). Africanized bees extend their distribution in California. *PLoS ONE*, *13*(1), e0190604. https://doi.org/10.1371/journal.pone.0190604
Lister, B. C., & Garcia, A. (2018). Climate-driven declines in arthropod abundance restructure a rainforest food web. *PNAS*, *115*(44), E10397–E10406. https://doi.org/10.1073/pnas.1722477115
Loftus, J. C., Smith, M. L., & Seeley, T. D. (2016). How honey bee colonies survive in the wild: Testing the importance of small nests and frequent swarming. *PLoS ONE*, *11*(3). https://doi.org/10.1371/journal.pone.0150362
Loukola, O. J., Perry, C. J., Coscos, L., & Chittka, L. (2017). Bumblebees show cognitive flexibility by improving on an observed complex behavior. *Science*, *355*(6327), 833–836. https://doi.org/10.1126/science.aag2360
Machovina, B., Feeley, K. J., & Ripple, W. J. (2015). Biodiversity conservation: The key is reducing meat consumption. *Science of the Total Environment*, *536*, 419–431. https://doi.org/10.1016/j.scitotenv.2015.07.022
Maderson, S., & Wynne-Jones, S. (2016). Beekeepers' knowledges and participation in pollinator conservation policy. *Journal of Rural Studies*, *45*, 88–98. https://doi.org/10.1016/j.jrurstud.2016.02.015
Mallinger, R. E., Gaines-Day, H. R., & Gratton, C. (2017). Do managed bees have negative effects on wild bees?: A systematic review of the literature. *PlosONE*, *12*(12). https://doi.org/10.1371/journal.pone.0189268
Mann, S., & Dickinson, J. (1978). Obstacles to the development of a capitalist agriculture. *Journal of Peasant Studies*, *5*(4), 466–481. https://doi.org/10.1080/03066157808438058
Mannion, A. M., & Morse, S. (2012). Biotechnology in agriculture: Agronomic and environmental considerations and reflections based on 15 years of GM crops. *Progress in Physical Geography*, *36*(6), 747–763. https://doi.org/10.1177/0309133312457109
McIntyre, B. D., Herren, H. R., Wakhungu, J., & Watson, R. T. (Eds.) (2009). *International assessment of agricultural knowledge, science and technology for development: Synthesis report*. Washington: Island Press.
Mogren, C. L., & Lundgren, J. G. (2016). Neonicotinoid-contaminated pollinator strips adjacent to cropland reduce honey bee nutritional status. *Scientific Reports*, *6*. https://doi.org/10.1038/srep29608
Moore, J. (2010). The end of the road? Agricultural revolutions in the capitalist world-ecology, 1450–2010. *Journal of Agrarian Change*, *10*(3), 389–413. https://doi.org/10.1111/j.1471-0366.2010.00276.x
Moore, L. J., & Kosut, M. (2013). *Buzz: Urban beekeeping and the power of the bee*. New York: New York University Press.
National Agriculture Statistics Service. (2019). *2018 California Almond Acreage Report*. https://www.nass.usda.gov/Statistics_by_State/California/Publications/Specialty_and_Other_Releases/Almond/Acreage/201904almac.pdf
Nicholson, C. C. & Ricketts, T. H. (2019). Wild pollinators improve production, uniformity, and timing of blueberry crops. *Agriculture, Ecosystems, and Environment*, *272*, 29–37.
Nimmo, R. (2015). Apiculture in the Anthropocene. In: Human animal research network editorial collective (Ed.), *Animals in the Anthropocene: Critical perspectives on non-human futures* (pp. 177–199). Sydney: Sydney University Press.

Norfolk, O., Gilbert, F., & Eichhorn, M.P. (2018). Alien honeybees increase pollination risks for range-restricted plants. *Diversity and Distributions*, *24*(5). 705–713. https://doi.org/10.1111/ddi.12715

Oestrel, E. (1980). History of beekeeping in the United States. In *Agriculture Handbook 335*. Washington, D.C.: United States Department of Agriculture.

Ontario, Government of (2017). Neonicotinoid regulations. Retrieved from https://www.ontario.ca/page/neonicotinoid-regulations

Oreskes, N., & Conway, E. M. (2010). *Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. New York: Bloomsbury.

Palladino, P. (1996). *Entomology, ecology and agriculture: The making of scientific careers in North America, 1885–1985*. Amsterdam: Harwood Academic Publishers.

Park, D., Jung, J. W., Choi, B., Jakakodi, M., Lee, J., Lim, J., … Kwon, H. W. (2015). Uncovering the novel characteristics of Asian honey bee, *Apis cerana*, by whole genome sequencing. *BMC Genomics*, *16*(1). https://doi.org/10.1186/1471-2164-16-1

Partap, U., & Ya, T. (2012). The human pollinators of fruit crops in Maoxian county, Sichuan, China. *Mountain Research and Development*, *32*(2), 176–186. https://doi.org/10.1659/MRD-JOURNAL-D-11-00108.1

Pellett, F. C. (1938). *History of American beekeeping*. Ames, IA: Collegiate Press, Inc.

Pettis, J. S., VanEngelsdorp, D., Johnson, J., & Dively, G. (2012). Pesticide exposure in honey bees results in increased levels of the gut pathogen *Nosema*. *Naturwissenschaften*, *99*, 153–158. https://doi.org/10.1007/s00114-011-0881-1

Pisa, L. W., Amaral-Rogers, V., Belzunces, L. P., Bonmatin, J. M., Downs, C. A., Goulson, D., … Wiemer, M. (2015). Effects of neonicotinoids and fipronil on non-target invertebrates. *Environmental Science and Pollution Research*, *22*(1), 68–102. https://doi.org/10.1007/s11356-014-3471-x

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schwiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology and Evolution*, *25*(6), 345–353. https://doi.org/10.1016/j.tree.2010.01.007

Potts, S. G., Imperatriz-Fonseca, V. L., Ngo, H. Y., Biesmeijer, J. C., Breeze, T. D., Dicks, C. V., … Viana, B. F. (Eds.) (2016). *Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production*. Bonn: Germany Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Reinhard, J. (2015). Animal cognition: Bumble bees suffer 'false memories'. *Current Biology*, *25*(6), R236–R238. https://doi.org/10.1016/j.cub.2015.01.072

Reinhard, J., Srinivasan, M. V., & Zhang, S. (2006). Complex memories in honeybees: Can there be more than two? *Journal of Comparative Physiology A*, *192*(4), 409–416. https://doi.org/10.1007/s00359-005-0079-0

Roger, N., Michez, D., Wattiez, R., Sheridan, C., & Vanderplanck, M. (2017). Diet effects on bumblebee health. *Journal of Insect Physiology*, *96*(Jan), 128–133. https://doi.org/10.1016/j.jinsphys.2016.11.002

Royce, L. A., Rossignol, P. A., Burgett, D. M., & Stringer, B. A. (1991). Reduction of tracheal mite parasitism of honey bees by swarming. *Philosophical Transactions: Biological Sciences. B*, *331*, 123–129.

Sage, C. (2012). *Environment and food*. London: Routledge.

Schmel, D. R., Teal, P. E. A., Frazier, J. L., & Grozinger, C. M. (2014). Genomic analysis of the interaction between pesticide exposure and nutrition in honey bees (*Apis mellifera*). *Journal of Insect Physiology*, *71*(Dec), 177–190. https://doi.org/10.1016/j.jinsphys.2014.10.002

Schulte, C., Theilenberg, E., Muller-Borg, M., Gempe, T., & Beye, M. (2014). Highly efficient integration and expression of piggyBac-derived cassettes in the honeybee (Apis mellifera). *PNAS*, *111*(24), 9003–9005. https://doi.org/10.1073/pnas.1402341111

Seeley, T. D. (2010). *Honeybee democracy*. Princeton UP: Princeton.

Seeley, T. D., & Visscher, P. K. (2003). Choosing a home: How the scouts in a honey bee swarm perceive the completion of their group decision making. *Behavioral Ecology and Sociobiology*, *54*(5), 511–520. https://doi.org/10.1007/s00265-003-0664-6

Seide, V. R., Bernardes, R. C., Pereira, E. J. G., & Lima, M. A. P. (2018). Glyphosate is lethal and Cry toxins alter the development of the stingless bee *Melipona quadrifasciata*. *Environmental Pollution*, *243B*, 1854–1860.

Seitz, N., Traynor, K. S., Steinhauer, N., Rennich, K., Wilon, M. E., Ellis, J. D., … van Engelsdorp, D. (2016). A national survey of managed honey bee 2014–2015 Annual colony losses in the USA. *Journal of Apicultural Research*, *54*(4), 292–304.

Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. *Nature*, *485*, 229–232. https://doi.org/10.1038/nature11069

Sgolastra, F., Medryzcki, P., Bortolotti, L., Renzi, M. T., Tosi, S., Bogo, G., … Bosch, J. (2017). Synergistic mortality between a neonicotinoid insecticide and an ergosterol-biosynthesis-inhibiting fungicide in three bee species. *Pest Management Science*, *73*(6), 1236–1243. https://doi.org/10.1002/ps.4449

Simone-Finstrom, M., Borba, R. S., Wilson, M., & Spivak, M. (2017). Propolis counteracts some threats to honey bee health. *Insects*, *8*(2), 46. http://doi.org/10.3390/insects8020046

Simone-Finstrom, M., Li-Byarlay, H., Huang, M. H., Strand, M. K., Rueppell, O., & Tarpy, D. R. (2016). Migratory management and environmental conditions affect lifespan and oxidative stress in honey bees. Scientific Reports *6*, https://www.nature.com/articles/srep32023

Simone-Finstrom, M. D., & Spivak, M. (2012). Increased resin collection after parasite challenge: A case of self-medication in honey bees? *PLoS ON*, *7*(3), e34601. https://doi.org/10.1371/journal.pone.0034601

Smalling, K. L., Reeves, R., Muths, E., Vandever, M., Battaglin, W. A., Hladik, M. L., & Pierce, C. L. (2015). Pesticide concentrations in frog tissue and wetland habitats in a landscape dominated by agriculture. *Science of the Total Environment*, *502*, 80–90. https://doi.org/10.1016/j.scitotenv.2014.08.114

Suryanarayanan, S. (2015). Pesticides and pollinators: A context-sensitive policy approach. *Current Opinion in Insect Science*, *10*, 149–155. https://doi.org/10.1016/j.cois.2015.05.009

Suryanarayanan, S. (2016). Intractosoma: Toward an epistemology of complexity based on intra-acting bodies. *Engaging Science, Technology, and Society*, *2*, 322–330. https://doi.org/10.17351/ests2016.135

Suryanarayanan, S., & Beilin, K. (forthcoming). Milpa Melipona Maya symbioculture facing agribiotechnology in Yucatán. *ACME*, International Journal of Critical Geographies.

Suryanarayanan, S., & Kleinman, D. L. (2013). Be(e)coming experts: The controversy of insecticides in the honey bee colony collapse disorder. *Social Studies of Science*, *43*(2), 215–240. https://doi.org/10.1177/0306312712466186

Suryanarayanan, S., & Kleinman, D. L. (2014). Beekeepers' collective resistance and the politics of pesticide regulation in France and the United States. In S. Frickel, & D. J. Hess (Eds.), *Fields of knowledge: Science, politics, and publics in the neoliberal age* (pp. 89–122). West Yorkshire: Emerald Group Publishing Ltd.

Suryanarayanan, S., & Kleinman, D. L. (2016). *Vanishing bees: Science, politics and honey bee health*. New Jersey: Rutgers University Press.

Tesovnik, T., Cizelj, I., Zorc, M., Citar, M., Bozic, J., Glavan, G., & Narat, M. (2017). Immune related gene expression in worker honey bee (*Apis mellifera carnica*) pupae exposed to neonicotinoid thiamethoxam and Varroa mites (Varroa destructor). *PLoS ONE*, *12*(10). https://doi.org/10.1371/journal.pone.0187079

Tsing, A. (1995). Empowering nature, or: Some gleanings in bee culture. In S. J. Yanagisako, & C. L. Delaney (Eds.), *Naturalizing power: Essays in feminist cultural analysis* (pp. 113–143). London: Routledge.

Tsvetkov, N., Samson-Robert, O., Sood, K., Patel, H. S., Malena, D. A., Gajiwala, P. H., … Zayed, A. (2017). Chronic exposure to neonicotinoids reduces honey bee health near corn crops. *Science*, *356*(June 30), 1395–1397. https://doi.org/10.1126/science.aam7470

vanEngelsdorp, D., & Meixner, M. D. (2010). A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. *Journal of Invertebrate Pathology*, *103*, S80–S95. https://doi.org/10.1016/j.jip.2009.06.011

Vogt, M. (2017). Toward functional pollinator abundance and diversity: Comparing policy response for neonicotinoid use to demonstrate a need for cautious and well-planned policy. *Biological Conservation*, *215*, 196–212. https://doi.org/10.1016/j.biocon.2017.09.006

Weis, T. (2010). The accelerating biophysical contradictions of industrial capitalist agriculture. *Journal of Agrarian Change*, *10*(3), 315–341. https://doi.org/10.1111/j.1471-0366.2010.00273.x

Weis, T. (2013). *The ecological hoofprint: The global burden of industrial livestock*. London: Zed.

Woodcock, B. A., Bullock, J. M., Shore, R. F., Heard, M. S., Pereira, M. G., RedHead, J., & Pywell, R. F. (2017). Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. *Science*, *356*(June 30), 1393–1395. https://doi.org/10.1126/science.aaa1190

How to cite this article: Ellis RA, Weis T, Suryanarayanan S, Beilin K. From a free gift of nature to a precarious commodity: Bees, pollination services, and industrial agriculture. *J Agrar Change*. 2020;1–23. https://doi.org/10.1111/joac.12360